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The Stem Rust Epidemic of 1935 in Nebraska

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THE STEM RUST EPIDEMIC OF 1935 IN NEBRASKA 1/

By George L. Peltier, Plant Pathologist, Nebraska Agricultural Experiment Station; Marion Yount, Associate Pathologist, Division of Plant Disease Control, Bureau of Entomology and Plant Quarantine; and C. A. Suneson, Assistant Agronomist, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture.

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The Prologue

A succession of dry years culminating in the disastrous drought of 1934, depleted soil moisture reserves to the lowest ebb in the history of agriculture in Nebraska. Although sufficient precipitation occurred in September of 1934 to moisten the top soil to a point favorable for planting and subsequent germination of fall-seeded grains, in all but the western third of the State it was deficient throughout the winter and early spring. From October, 1934, through March, 1935, and in some localities even into April, rainfall was much below normal and together with an unusual amount of drifting soil, conditions were very unfavorable for over-wintering and normal development of winter grains. On the other hand, during the usual seeding period for spring small grains temperatures were below normal, so much so that seeding was unseasonably delayed, while the spring development of winter grains was inhibited to a large extent.

The combinations and sequence of factors, including poor seed stocks, lack of soil moisture for normal fall growth in some localities, a warm, open winter, soil drifting and blowing (particularly in the southern and western parts of the State), excessive pasturing, delayed spring development due in part to lack of soil moisture, and a cold, wet April and May, all contributed to the delayed heading of winter grains. Similarly, a dry March and a cold, wet April not only delayed seeding of the poor seed available but inhibited their germination and subsequent development to a point that proved decidedly disadvantageous when first rust and later heat were encountered as the small grains were maturing. The set of factors enumerated above for both winter and spring grains also resulted in some abandonment, lighter stands, and retarded development of the plants, additional factors which were reflected in part by the low resultant yields of all small grain crops.

1/ Paper No. 176 of the Journal Series of the Nebraska Agricultural Experiment Station.

By June 1 all small grains while delayed in their development, were making a rapid, lush growth and were in an excellent condition for stem-rust attacks in the eastern half of the State.

The Setting

Weather Conditions

Temperature departures for the State from the normal for January (+4.6 degrees), February (+8.5 degrees), and March (+6.5 degrees), totaled +19.6 degrees F., a rather striking figure, whereas precipitation for the same period was approximately 35 percent of the normal. In order to visualize this deficiency of precipitation, Figure 1 is presented primarily to point out the dry areas in the State. The weather for the first three months of 1935 can be classified as much warmer and drier than usual.

In contrast to these conditions, the temperature departure for April (-3.5 degrees) and May (-6.3 degrees) was -9.8 degrees, and the precipitation was about 159 percent of the normal. The precipitation for these two months alone in many localities approached the total rainfall for the entire year of 1934. The distribution of this unprecedented precipitation is shown in Figure 2. It will be noted that all parts of the State received a generous amount of rainfall during these two months.

It has been pointed out by Peltier 2/ that low temperature is a limiting factor in the development of primary stem-rust infection and subsequent development of uredia, whereas the lack of an even distribution of sufficient precipitation is the major inhibiting factor in the development of subsequent urediosporic generations. For this reason the weather for June and July will be presented by weekly intervals (Figs. 3, 4, 5, 6, 7, and 8).

The weather for the first week in June was characterized by mean temperatures ranging in the fifties over most of the State and by a moderate rainfall fairly well distributed over the entire State. Only in the south and southeastern districts were mean temperatures high enough to favor primary infection, although they were not optimum by any means.

During the second week in June, temperatures throughout the State were nearer optimum for primary infection and production of uredia, but rainfall was spotty and rather light at many points.

2/ Peltier, G. L. Relation of Weather to the Prevalence of Wheat Stem Rust in Nebraska. Jour. Agr. Res. 46: 59-73, 1933.

With the exception of some counties in the western end of the State, both temperatures and precipitation were exceedingly favorable for stem-rust infection during the entire third and fourth week of June, and, as will be pointed out later, it was during this interval that the stem-rust epidemic in Nebraska was in the making. Further, it was also in this period that strong southern winds prevailed for several consecutive days, which carried a profuse rust inoculum to all parts of the State. For the State as a whole, the weather in June was cool (2.6 degrees below normal) with about a normal rainfall (3.73 inches) and with more than normal-humidity conditions ideal for heavy infection and rapid development of many urediosporic generations.

Beginning in early July mean temperatures rose abruptly into the eighties and, with few exceptions in the western third of the State, remained at these points throughout the month. On the other hand, rainfall decreased and was very spotty. The month of July was warm (+6.3 degrees F.) and dry (2.0 inches below normal) with sunshine much above normal - conditions very unfavorable for the normal maturity of the delayed winter and spring grains. Thus while weather greatly favored stem-rust development during the last two weeks of June, it was decidedly unfavorable in July for maturation of all grains, so that shriveled and light kernels resulted to a large extent from a combination of stem rust and heat to produce low yields.

To summarize: The early growing season of 1935 was extremely erratic, the first three months of the year being much warmer and drier than usual, whereas April and May were cooler and wetter than normal. By June 1 all grains, although delayed in their normal development, were making a rapid and excessive growth, but these same conditions also favored infection and rapid development of progressive urediosporic generations of stem rust. It was during the last two weeks in June that the rust epidemic got under way in the eastern two-thirds of the State. July was hot and dry in this same area and while it inhibited further urediosporic generations, the heat hastened the abnormal ripening of the immature grains because of the great stress of excessive transpiration and deficient soil moisture. Thus stem rust and heat alone, or in combination, cut the yield of all grains throughout the State.

Relation of Weather to Host Development

There is no need, in the light of the climatic data presented, to dwell upon the delayed development of both winter and spring grains. Because of a sequence of factors, heading was delayed, ripening was late and the duration of the fruiting period lengthened. The only accurate data available to show this point are those obtained at Lincoln with Turkey Red winter wheat. For a comparison with the prevailing conditions in

1935, the lengths of the fruiting period for the stem-rust epidemic years of 1904, 1916, 1919, and 1920 were employed. In Table 1 the time of heading and ripening and the length of the fruiting period of Turkey Red winter wheat for the above-mentioned years at Lincoln are listed. The length of the fruiting period varies from four to five and one-half weeks, while in 1935 it was only one day short of five weeks. During this long interval, especially when abundant inoculum is at hand shortly after the plants head, it can be readily seen that many urediosporic generations can occur.

Table 1.-Seasonal variation in the time and length of the fruiting period of Turkey Red winter wheat for four years during which stem-rust epidemics occurred for comparison with that of 1935 at Lincoln, Nebraska.

Year	Date of heading	Date of ripening	Length of fruiting period
			Days
1904	June 4	July 13	39
1916	June 2	July 7	35
1919	June 3	July 3	30
1920	June 9	July 7	28
1935	June 4	July 8	34

To ascertain the influence of weather on the length of the fruiting period, the mean temperatures, total precipitation, and the number of rainy days for the actual period for the above-mentioned years are given in Table 2. During this period the mean temperatures were ideal for rust infection and rapid development. The total rainfall and the number of rainy days give an idea of the distribution of the rainfall. It will be noted that an even distribution over many days is quite essential for stem rust and in those years where this occurs, the stem rust epidemics have been more severe. Apparently the season of 1935 at Lincoln was the most favorable for rust of any epidemic year since 1904 in this respect.

The data listed for Lincoln, however, can not be considered typical of the whole State. Peltier 3/ has pointed out that if Nebraska were pivoted at the southeast corner and moved in a 90 degree angle to the north, the western part would lie in Minnesota. The altitude, moreover, increases at the rate of one foot for every seven miles westward across the State, so that with the exception of precipitation, conditions in the spring wheat area in northwest Nebraska are somewhat similar to those in the spring wheat area in Minnesota and the Dakotas. Hence in western Nebraska the Turkey Red winter wheat heads from 4 to 7 days and ripens from 7 to 14 days, later than at Lincoln, while the lengths of the fruiting period are intermediate between these two widely removed localities.

Table 2.-Influence of weather on the length of the fruiting period of Turkey Red winter wheat at Lincoln, Nebraska.

Year	Length of fruiting period	Mean temperature	Precipitation	Rainy Days
	Days	°F.	Inches	Number
1904	39	69.2	6.85	21
1916	35	70.5	3.14	11
1919	30	75.7	3.74	11
1920	28	73.2	2.10	10
1935	34	71.9	4.15	14

Amount, Time of Appearance, and General Dissemination of Initial Inoculum

The drought and heat of 1934 prevented to a large extent the over-summering of the few teliospores produced on grains. These same conditions also inhibited the growth of volunteer wheat in the fall, so that only an occasional telium was found in late fall on volunteer grains and grasses.

3/ Peltier, G. L. Op. cit. (footnote 2).

Beginning in early April, 1935, barberry bushes in seven counties located in the eastern third of the State were systematically observed for the presence of aecia. During the course of several months no aecia were found on these bushes; in fact not a single bush was found in Nebraska during 1935 with either pycnial or aecial infection. Few, if any, barberry bushes were infected in 1935, although weather conditions favorable for sporidial infection were at hand. Apparently the limiting factor was the absence of viable teliospores. Little, if any, stem rust in Nebraska resulted from aecial infection but originated from a source other than the barberry.

No doubt as a result of an unusually warm winter in the southern grain-growing sections more than the normal number of urediospores overwintered over an extended area in Texas. That urediospores reached southern Nebraska quite early in the season was confirmed by a series of slide exposures. Furthermore, the number of urediospores increased very rapidly during the latter part of May and the first week in June in areas where temperatures were high enough for primary infection to occur.

As early as the week beginning May 15 an average of 120 urediospores were caught on the slides during each of three 24-hour periods in Nuckolls County. Only a few spores were caught at points in the eastern third of the State as far north as Madison County (Fig. 9). To determine the number of spores falling per square foot over a 24-hour period, the number of urediospores found on the exposed slides should be multiplied by 48. The following week an average of 560 spores for each of two slide exposures were obtained in Nuckolls County, while only a few spores were caught occasionally as far north as Holt County (Fig. 10). By June 4 the concentration of urediospores in Nuckolls County had increased to an average of 2,136 spores per slide during each of two 24-hour exposures. In other words, urediospores were falling at the rate of over 100,000 per square foot, surely a tremendous number, yet in spite of this high concentration of spores only a few were collected at other points in the State north of Nuckolls County (Fig. 11).

During the week beginning June 5 a new concentration of spores was found in Seward and Lancaster Counties, while once again only a few spores were caught on the exposed slides to the north and west in the State (Fig. 12). The following week there was an increase in numbers of spores on the exposed slides in Lancaster and in Buffalo counties, as well as a slight increase in the western part of the State (Fig. 13). In the week beginning June 19, the spores collected on the exposed slides in Lancaster County averaged over 2,000 per slide. They also increased manyfold at a number of points in western Nebraska (Fig. 14). The following week a total of 34,929 spores were caught during five 24-hour exposures, or almost 7,000 spores per slide in Lancaster County, that is at the rate of approximately 335,000 spores per square foot. A high

concentration of spores was also found in Hitchcock County and it is quite apparent that they were well distributed in fairly large numbers throughout the western part of the State (Fig. 15). By the first week in July the slide exposures showed that the number of spores in western Nebraska increased almost ninefold over the preceding week (Fig. 16), and during the following week an average of 4,000 spores for each of four slide exposures were obtained in Box Butte County.

On the basis of the slide exposures it can be assumed that during the last two weeks in May a fairly large primary infection occurred and a subsequent high concentration of inoculum developed in Nuckolls County and possibly in the surrounding area, especially to the south and west where suitable temperature for primary infection prevailed. This area was apparently the focus for the rust inoculum, which progressively reached all sections of Nebraska. About June 5 another area of concentrated primary infection developed with Lancaster County as the center, which during the interval up to July 1 produced a large amount of inoculum. Local centers of rust concentration later developed in Buffalo, Hitchcock, Cheyenne Counties, and finally in Box Butte, where by the middle of the month, 24-hour slide exposures averaged 4,000 spores per slide or almost 200,000 per square foot in the last-named county.

During the second and third week of June there were at least four occasions when southerly winds prevailed, as a consequence of low-pressure areas advancing from the west of Nebraska. On June 23 and 24, because of two advancing low-pressure areas, one moving towards the spring-wheat area and the other approaching the winter-wheat belt, strong southerly winds prevailed over the entire Great Plains region, followed by generous amounts of precipitation throughout the area. It was at this time that the large concentrations of inoculum in south-central Nebraska and adjacent areas were distributed in a fan-shaped fashion to the north. This large amount of inoculum was sufficient to produce a widespread primary infection, heavy enough in itself to cause considerable damage to wheat, since ideal weather conditions prevailed and the grain plants were at the stage of development most receptive to rust infection in most areas of the State.

The first uredia were collected in Jefferson June 7, in Lancaster June 11, in Kimball July 1, and in Box Butte County July 6, although from evidence presented above, primary uredia probably developed earlier in Nuckolls and near-by counties. Mature uredia were first noted at Lincoln on June 11. If the weather data for a two-weeks period prior to this date are analyzed, it is found that the mean temperature was 62.5 degrees F. and the total precipitation was 3.41 inches, including 8 rainy days. While mean temperatures below the optimum prevailed for primary infection, other conditions were ideal.

The number of days from the first appearance of primary uredia to the ripening of winter wheat was 27, or 1 day short of 4 weeks, a rather long period. During this interval the mean temperature was 75.4 degrees F., the total rainfall was 6.52 inches, with 15 rainy days. The number of cloudy days and the relative humidity were both greater than normal for this same period--conditions ideal for the rapid development of secondary and succeeding urediosporic generations. In fact the weather was more ideal for rust infection during June of 1935 at Lincoln than at any time since stem rust investigations were initiated in 1920.

A study of the climatic data at North Platte and Scottsbluff reveals the fact that the weather was much more favorable for rust in 1935 than in 1923 when stem rust assumed epidemic proportions in western Nebraska, since both temperature and precipitation were above the normal. Rust epidemics in western Nebraska, like those in the spring-wheat areas of Minnesota and the Dakotas, are possible, other factors being favorable, only when temperatures are above the normal for July and the forepart of August. An even distribution of rainfall well above normal is also an essential prerequisite in western Nebraska. In contrast to these requirements a mean temperature somewhat below the normal during June and the forepart of July, together with ample rainfall well distributed are essential for rust epidemics in the eastern half of Nebraska. Thus the entire sequence and progression of factors necessary for a statewide stem-rust epidemic was at hand and they continued to favor the further development of stem rust in the eastern two-thirds of the State up until the first week in July, when hot, dry weather set in which not only inhibited the further spread of rust but stimulated the premature ripening of all small grains.

The Stem Rust Epidemic

Survey Methods:- In order to determine with some degree of exactness the severity of stem rust the following procedures were employed. Fieldmen entered into a grain field at least 3 or more rods, selected a representative area, and grasped within an arm's reach at least 50 or more stems which were cut off at the base. The prevalence and severity of stem rust were then checked with the U.S.D.A. standard scale for estimation of rust. Detailed notes of the stage of maturity, the presence of other disease, topography and other pertinent observations were made. The bundle of stems was given a number and sent to the plant-pathology laboratory, College of Agriculture, Lincoln. In this way upwards of 600 samples of wheat alone were collected in various parts of the State, as shown in Figure 17.

When all the samples were assembled one of the writers determined the varieties and the following data were obtained: the number of spikelets per head (average of 10 representative heads from each bundle), the number of kernels per head, the weight of 100 kernels from each sample, and the amount of kernel shriveling as determined from Plate 1, which was prepared from selected kernels of Cheyenne winter wheat. As the correlation between the severity of stem rust and the degree of shriveling was complicated by the effects of the heat in July, which hastened the premature ripening of all small grains, the data will be held in abeyance until a complete analysis can be made.

In order to check the data on stem rust severity, approximately 900 replies to a questionnaire were obtained from grain growers and more than 400 reports were received from grain dealers distributed over the State. It is one of the objects of this paper to compare and discuss the data on stem rust severity on the basis of these three distinct sources of information.

Results:- On the basis of the collections, the distribution of which is shown in Figure 17, Table 3 has been prepared listing the severity of stem rust by crop districts for the various grains. It will be noted that stem rust of rye (*Puccinia graminis secalis*) averaged less than 1 percent in severity and so far as this crop was concerned, no measurable damage occurred. As has been pointed out by Peltier 4/, with the continued eradication of the barberry, which is apparently the only source of rye stem rust in Nebraska, it is gradually disappearing. The fact that rye stem rust was scattered and very slight during the favorable season of 1935, indicates that the above interpretation is correct.

Only in the central district was more than 1 percent severity recorded of oats stem rust (*Puccinia graminis avenae*), and it is evident that for some reason or other inoculum was rather sparse and reached the State late in the season, so that, like rye, this crop escaped measurable losses in most parts of Nebraska. Barley, on the other hand, with few exceptions showed a severity of stem rust approaching that of winter wheat in some of the crop districts, indicating that barley was attacked almost exclusively by wheat stem rust (*Puccinia graminis tritici*).

4/ Peltier, G. L. Some aspects of the spread of stem rust. Zentbl. Bakt. (etc.) Abt. II, 78: 525-535, 1929.

Table 3.-Severity of stem rust in Nebraska (1935) by crop districts

Crop districts	Wheat		Oats		Rye		Barley	
	Collections	Stem rust severity	Collections	Stem rust severity	Collections	Stem rust severity	Collections	Stem rust severity
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Northwest	77	37	4	-1	1	T	8	37
North	6	27	-	-	1	T	-	-
Northeast	25	16	5	T	9	-1	11	3
Central	44	28	2	8	2	-1	5	19
East	191	26	22	-1	14	-1	6	8
Southwest	51	12	3	-1	3	-1	5	23
South	71	17	10	-1	4	-1	7	14
Southeast	98	7	19	-1	12	-1	2	9
Average	563	21	65	$\pm$1.5	46	-1	44	16

Naturally the greatest rust severity on wheat was found in the northwest crop district, since spring wheat is confined to a large extent to this area. The least stem rust occurred in the southeast district. A stem-rust severity greater than 25 percent was found in the east, central, and north districts and 17 percent or less in the crop districts bordering on the Kansas state line and in the northeast district, where wheat is not a major crop. In order that a more extensive view of the wheat stem rust situation may be obtained, the rust severity is listed by counties in Figure 18. Here again, it will be noted that rust was of minor importance in the southeastern, northeastern, and southwestern corners of the State, while it was quite severe in the east-central, central, and northwestern counties.

The progress of stem rust can almost be visualized across Nebraska by the degree of rust severity recorded on the matured grain. It will be recalled that a large concentration of inoculum was built up quite early

in the season in the south-central tier of counties, with Webster County as the center. This large concentration of spores served as a source of primary infection, first in the east-central counties and somewhat later in an area with Buffalo County as a center; and finally, with the southerly winds of June 23 and 24, inoculum was distributed throughout northern and western Nebraska to produce an extensive and heavy primary infection the first week in July. It is also evident from Figure 18 that the dissemination of urediospores from this source was in a fan-shaped fashion, since in the two southern corners only slight damage to wheat resulted from rust.

Only in the northwest district are both winter and spring wheat grown to any extent, although a few scattered fields of spring wheat are grown each year in eastern Nebraska. It is of interest to compare the rust severity in this area, not only on the two types of wheat but on the varieties commonly grown. Table 4 has been prepared to show such a comparison. The durum wheats showed the least rust severity (20 percent), the winter wheats followed closely (23 percent), and the spring wheats were most severely attacked (33 percent). Considerable differences in rust susceptibility between spring wheat varieties occurred. For example, Ceres, a supposedly resistant variety, showed more rust severity than Reward, a commonly grown spring wheat, although the number of spikelets with kernels was 78 percent as against 64 percent for Reward and the average weight of kernels was also greater.

No appreciable differences in rust susceptibility were noted between hard red winter wheat varieties commonly grown in Nebraska, but they were less susceptible than the soft red winter wheats. It can be safely stated that no variety of wheat escaped rust and that the physiologic races prevalent in Nebraska during the 1935 season were able to infect all types and varieties of wheat to a varying extent since all durums, winter, and spring wheats, including Ceres, were collected in the State with varying amounts of stem rust.

In the questionnaire sent out to the grain growers, they were asked to indicate the amount of stem rust present on the stems of the grains under the following headings: None, trace, moderate, and heavy. The reports for both winter and spring wheats are shown in Figures 19 and 20. In the main, the heaviest amounts of stem rust were reported by the growers from the same areas that were observed by our fieldmen. Here again the trend was the same; a light infection occurred in the two southern corners and in the northeastern part of the State, while larger amounts of rust were reported from the east-central section, the central half, and the western third of the State. Attention is directed to the heavy amount of rust in the fields in south-central Nebraska, where large amounts of inoculum were built up early and which served as the source of primary infection for most of Nebraska. In the northwest district stem rust of winter wheat was present in every field

Table 4.- Relative severity of stem rust in the northwest crop district of Nebraska on various kinds of wheat.

Kind of wheat	Collections	Average severity of stem rust	Average spikelet per head	Average Kernels per head	Average kernels per spikelet	Average weight of 100 kernels
	Number	Percent	Number	Number	Percent	Grams
Winter wheats	18	23	32.8	25.1	77	2.10
Durums	5	20	33.0	27.1	82	2.00
Reward	22	38	34.2	22.1	64	1.34
Miscellaneous spring wheats	9	41	32.6	21.6	66	1.80
Dixon	5	51	32.8	22.8	70	1.00
Ceres	10	51	32.2	25.1	78	1.53
Java	4	56	31.2	22.5	72	1.66
All spring wheats	56	33	32.8	23.5	72	1.58

but one reported by the growers, and in most instances moderate to heavy amounts of stem rust were indicated. Only a few scattered fields of winter wheat escaped rust in this area, as can be noted in Figure 19. Stem rust on spring wheat was much more severe, being heaviest again in the northwest district. Not one report of a field of spring wheat free from stem rust was received from this area.

The growers for the most part indicated only a trace to no stem rust on oats, although here and there, primarily in the eastern half of the State, a moderate to a heavy infection was reported. A similar statement can be made for the prevalence and severity of rye stem rust, although even fewer reports of a moderate to heavy infection were received for rye. In other words, little or no measurable loss from rye stem rust was reported by the growers and although more oats stem rust was reported, the losses were slight. Stem rust on barley, however, was much heavier and many growers indicated a moderate to a heavy amount on this grain. It is quite apparent from these results that the wheat

stem rust was involved rather than rye stem rust. Thus, while nearly 900 reports from the grain growers reveal a heavier infection than found by our fieldmen, the trends are the same as in the distribution of stem rust severity on the various grains, although perhaps they accentuated their losses somewhat. At least the reports from the growers themselves served as a valuable adjunct in the stem-rust survey.

A somewhat more elaborate questionnaire was forwarded to the grain dealers through the cooperation of Mr. A. E. Anderson, Federal Agricultural Statistician for Nebraska. They were asked to report the average yield and test weight per bushel, the estimated loss in percentage from stem rust, and the percentage loss from the combination of hot, dry weather for the various grain crops. More than 400 reports were returned. Figure 21 not only indicates the location and distribution of the grain dealers but also the estimated combined loss in percentage from stem rust of winter and spring wheat. It will be seen that the trend of stem rust damage to wheat is similar to those already pointed out from two diverse sources. As in the data obtained from the grain growers, however, the estimated losses are somewhat accentuated. This fact is more clearly brought out in Figures 22 and 23, where the average yield in bushels, the estimated percentage loss from stem rust and the percentage loss from heat are listed by counties for winter and spring wheat, respectively.

Note the low yields of winter wheat in those areas where stem rust was most severe. The south crop district, with yields as low as 3 bushels per acre, as in Webster County, was the center of early infection. Increasingly larger yields were reported in the southern tier of counties, as distance from the center increased and in the two southern corners yields were fairly good and rust damage much lower. Throughout the remainder of the State yields were below normal. In general there is a correlation between yields and the extent of loss attributed to a combination of stem rust and heat, although in many instances the combined losses are intensified. It is apparent from Figure 23 that yields of spring wheat were extremely low, especially in the northwest district and, strange as it may seem, higher yields were obtained in the eastern third of the State where normally adverse climatic conditions and stem rust prevalence usually are unfavorable for the maturity of this crop. In other words, environmental conditions for stem rust were ideal in 1935 in northwestern Nebraska.

As in the case of the data collected by the writers and those reported by the grain growers, very little stem rust of oats was indicated and with the exception of a few localized areas, yields of around 30 bushels per acre were estimated by the grain dealers over the State as a whole. This same situation prevailed in northwest Nebraska and had inoculum of oats stem rust been prevalent in any amount, the severity of this rust would have been much greater in this area. Even less stem

rust of rye was reported by the grain dealers. Low yields in some instances, however, especially in the early season in the dry areas in the northwest and south districts, were listed. The estimated percentage of loss due to stem rust on barley was much higher than in either of the two above-mentioned cereals, and in some sections of the State the loss in barley approached the losses in winter wheat.

The data received from the grain dealers, then, supplemented in a large measure those obtained from the other two sources in indicating the relative prevalence and severity of stem rust on the small grains, although like the reports from the grain growers, there was a tendency to intensify the estimated loss due to stem rust. From the standpoint of survey methods, the three sources of information showed more or less the same trends in that they corroborated one another so far as the prevalence and severity of stem rust was concerned. Thus from the viewpoint of public and private crop disease reporting, all three sources furnished a picture of the stem rust epidemic in Nebraska.

In conclusion it can be stated that all three sources of information served to show the 1935 rust epidemic to be as severe as any previous epidemic in Nebraska. The primary source of this epidemic was the large amount of inoculum built up early in the south-central Nebraska and adjacent areas in Kansas, as the result of perhaps larger numbers than usual of wind-blown urediospores from the South. This inoculum was sufficiently large to produce a heavy primary infection throughout most of Nebraska. Further, no variety of either spring or winter wheat commonly grown in the State showed resistance to the prevailing physiologic races. Thus Kanred was apparently as severely rusted as Turkey Red and Ceres as Marquis or Reward.

The Hot, Dry Winds

The sequence of factors responsible for the delayed spring development of all cereal grains have already been enumerated, together with the fact that soil moisture reserves were at their lowest ebb at the time of spring seeding. Although mean temperatures for the first three months of the year were much above normal and precipitation was highly deficient as well, the following three months were characterized by mean temperatures below normal with precipitation much in excess of normal. Under the latter conditions the slow-starting grains were pushed rapidly during June into a heavy lush growth in the eastern half of the State and when the mean temperatures rose abruptly into the eighties in early July and precipitation declined rapidly, the plants soon depleted the scanty soil moisture and as a consequence the maturing grain suffered severely from a moisture deficiency. The heads did not fill and the kernels became shriveled, resulting in disappointing yields throughout most of Nebraska, even apart from the ravages of rust.

It is exceedingly difficult, of course, to determine the exact amount of shriveling due to stem rust and heat alone. A preliminary study, however, of the more than 600 samples of grain show that upwards of one-half of the shriveling can be accounted for by the weather, including insufficient soil moisture to carry on the normal development of the plants, aided by high temperatures and drying winds conducive to excessive loss of water from the top soil and the shallow-rooted plants. Likewise Figures 22 and 23 also reveal that the grain dealers in estimating the losses due to these conditions considered almost half of the losses in wheat to be due to hot, dry weather.

For the present the estimated amount of shriveling as reflected in part by the low yields and in part by the test weights due to hot weather, must be analyzed from the data at hand. In Table 5 are listed the stem-rust severity in percentage in the various small grains as determined by the writers and the yields in bushels per acre and the test weights in pounds per bushel as estimated by the grain dealers for the eight crop districts of Nebraska.

Low yields of rye in the northwest and south crop districts can be primarily attributed to the exceedingly dry winter in these areas, which was very unfavorable to the normal overwintering of this cereal. Further, no measurable loss from rye stem rust was recorded and since the yield of this crop was below normal and the test weights were also low, grading No. 2 or even less, these losses must be attributed almost entirely to the adverse conditions, including the hot, dry weather of July, 1935. This can be well illustrated by pointing out the low rye yields of 12 bushels per acre estimated for the northwest district, where the test weights averaged 54 pounds to the bushel as compared with yields averaging 23 bushels per acre and test weights of only 52 pounds to the bushel in the north district.

Since rye normally ripens somewhat earlier than winter wheat, rye did not receive the full effect of the heat as did winter wheat. The average winter wheat yield for the entire State was estimated by the grain dealers as 13 bushels per acre, whereas the average yield of rye was 5 bushels more per acre. Further, the test weights were the same for both crops, which again reflects the greater damage to winter wheat by the combination of both rust and heat. Even where stem rust damage was slight, yields were disappointing and test weights low, the wheat grading No. 3 or less, as in the southeast district. Other than in the northwest district, where stem rust was most severe, heat took its toll in all other parts of the State.

Barley, a spring-seeded crop, suffered still more severely from heat as reflected primarily in the low test weights over the entire State, the average being only 40 pounds per bushel. The effects of stem rust in reducing yields are apparent in the northwest and southwest districts, although so far as shriveling is concerned, heat was a more important factor than stem rust over the entire State.

Table 5.-The relative stem rust severity compared with the average yield per acre and pounds per bushel of the various small grains grown in the eight crop districts in Nebraska in 1935

Crop districts	Winter wheat			Spring Wheat			Oats			Rye			Barley		
	Stem rust se-verity a/	Yields per acre	Test weights per bu.	Stem rust se-verity	Yields per acre	Test weights per bu.	Stem rust se-verity	Yields per acre	Test weights per bu.	Stem rust se-verity	Yields per acre	Test weights per bu.	Stem rust se-verity	Yields per acre	Test weights per bu.
	%	Bu.	Lbs.	%	Bu.	Lbs.	%	Bu.	Lbs.	%	Bu.	Lbs.	%	Bu.	Lbs.
North-west	37	11	53	-	6	48	-1	32	32	T	12	54	37	20	37
North	27	15	52	-	8	47	-	29	27	T	21	54	-	25	39
North-east	16	14	51	-	9	46	T	36	27	-1	23	52	3	29	40
Central	28	12	53	-	9	50	8	33	27	-1	17	53	19	26	41
East	26	16	55	-	12	51	-1	35	26	-1	22	53	8	30	41
South-west	12	15	54	-	10	52	-1	31	29	-1	18	54	23	22	38
South	17	10	53	-	8	53	-1	27	27	-1	13	52	14	24	40
South-east	7	14	55	-	8	53	-1	29	25	-1	18	54	9	23	43
Average	21.0	13	53	-	9	50	±1.5	32	28	-1.0	18	53	16	24	40

a/ All wheats

Spring wheat yields averaged only 9 bushels per acre with a test weight of only 50 pounds per bushel for the entire State. As was to be expected spring wheat suffered a greater combined damage from stem rust and heat than any other of the small grains, since it is a late-maturing grain. Here again the damage of either one of the factors can be illustrated. In the northwest district, yields of 6 bushels to the acre of spring wheat testing 43 pounds to the bushel were obtained, where rust severity was found to be exceedingly high, as contrasted with yields of 9 bushels to the acre of wheat testing only 46 pounds to the bushel with rust severity less than half as great in the northeast district where heat damage was more pronounced.

The prevalence and severity of oats stem rust was somewhat spotted but on the whole it did relatively little damage since yields averaged 32 bushels per acre for the entire State.

Only in the northwest district, however, were the test weights up to normal and, as has been pointed out previously, it was in this section of the State that the least heat damage occurred in the other grains. Thus what measurable damage in oats occurred was due not primarily to stem rust but to heat and other adverse factors.

<u>To summarize</u>:- The damage occurring to rye in 1935 in Nebraska can be attributed solely to adverse weather conditions. In the case of oats upward of 90 percent of the lowered yields and low test weights can be attributed to heat and the remainder to stem rust. The loss in barley due to heat and rust can be roughly divided as 40 percent from stem rust and 60 percent from heat. Winter wheat losses, on the other hand, can be assessed on a 50 - 50 basis between stem rust and heat. Losses in spring wheat, however, can be divided on the basis of a 60 percent damage due to stem rust ravages and 40 percent due to heat. These estimates are based on a compilation of the data from all three sources, and do not take into consideration the many fields of grain, which owing to various conditions were not harvested, nor the damage resulting from leaf rusts. It is quite apparent, therefore, that stem rust took its toll of spring and winter wheats and barley but that the hot, dry winds were responsible primarily for the poor filling of the heads and shriveled berries, which resulted in extremely low test weights, while the loss actually occurring in rye and oats was due for the most part to heat alone.

The Epilogue

In spite of an unusually erratic season, the sequence of factors necessary for a stem rust epidemic was fulfilled in Nebraska in 1935. These factors are, delayed seeding (spring wheat) or delayed early spring development (winter wheat), late heading and ripening, and a long fruiting period with favorable weather for an extensive infection by a large amount of initial inoculum about the time of heading of the winter grains.

It is interesting to speculate on what the losses from stem rust might have been if the weather in July had remained favorable for further rust development. It may be surmised, however, that the sudden coming of hot weather in early July perhaps reduced the final yield of all grains in the eastern half of the State more than if stem rust had continued its ravages. At any rate, so far as Nebraska is concerned, the losses directly due to heat will approximate those due to stem rust, if all the grain crops are considered.

Whenever the sequence and combination of factors click, as they did in 1935, stem rust epidemics will occur in the future as they have prevailed in the past. Fortunately the many factors involved synchronize only in occasional years. The fact that stem rust epidemics may occur in the future should in no way deter the continued eradication of the barberry in the Great Plains area west of the Mississippi River, nor the intensive breeding of rust-resistant varieties of small grains. Through breeding rust-resistant varieties for those areas in Texas where urediospores normally overwinter, the prevention, or at least the mitigation of this annual source of stem rust can be made effective. Only when the two sources of rust are reduced or prevented will stem-rust epidemics disappear in the extensive wheat-growing area of the Great Plains region.

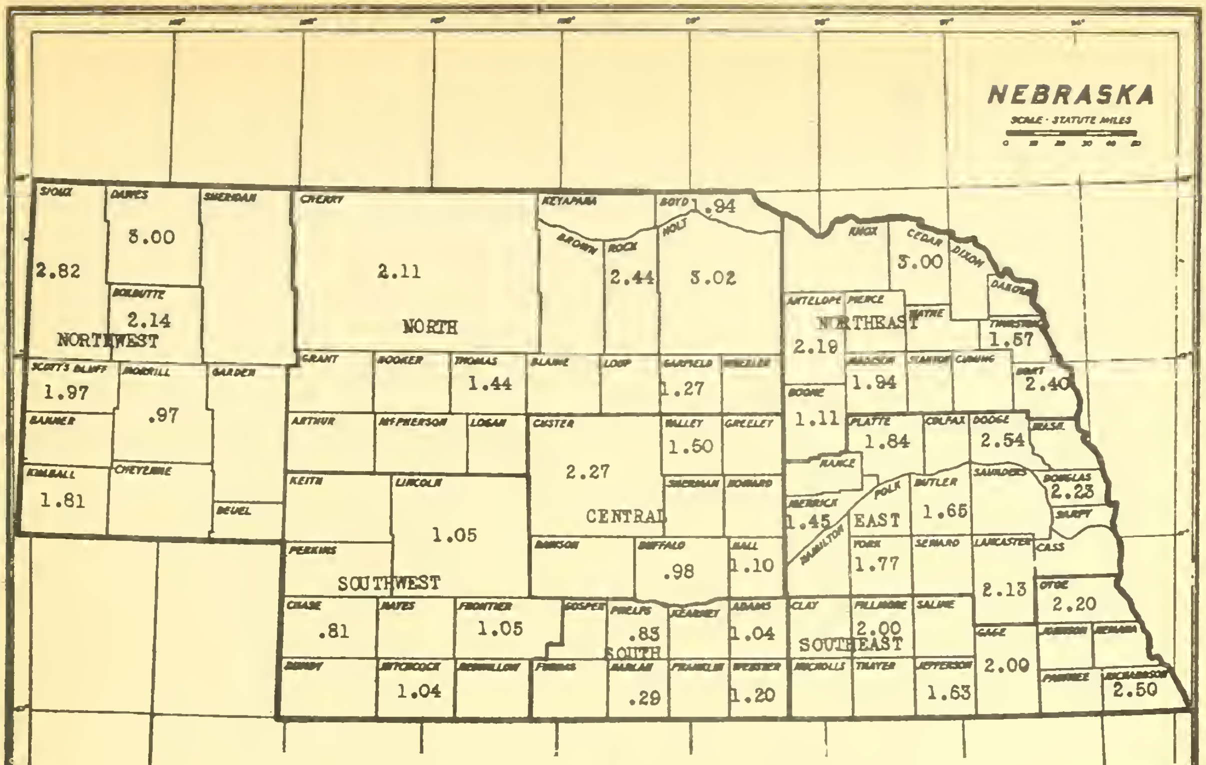

Fig. 1. Total precipitation from January 1 to March 31, 1935,
at 42 points in Nebraska.

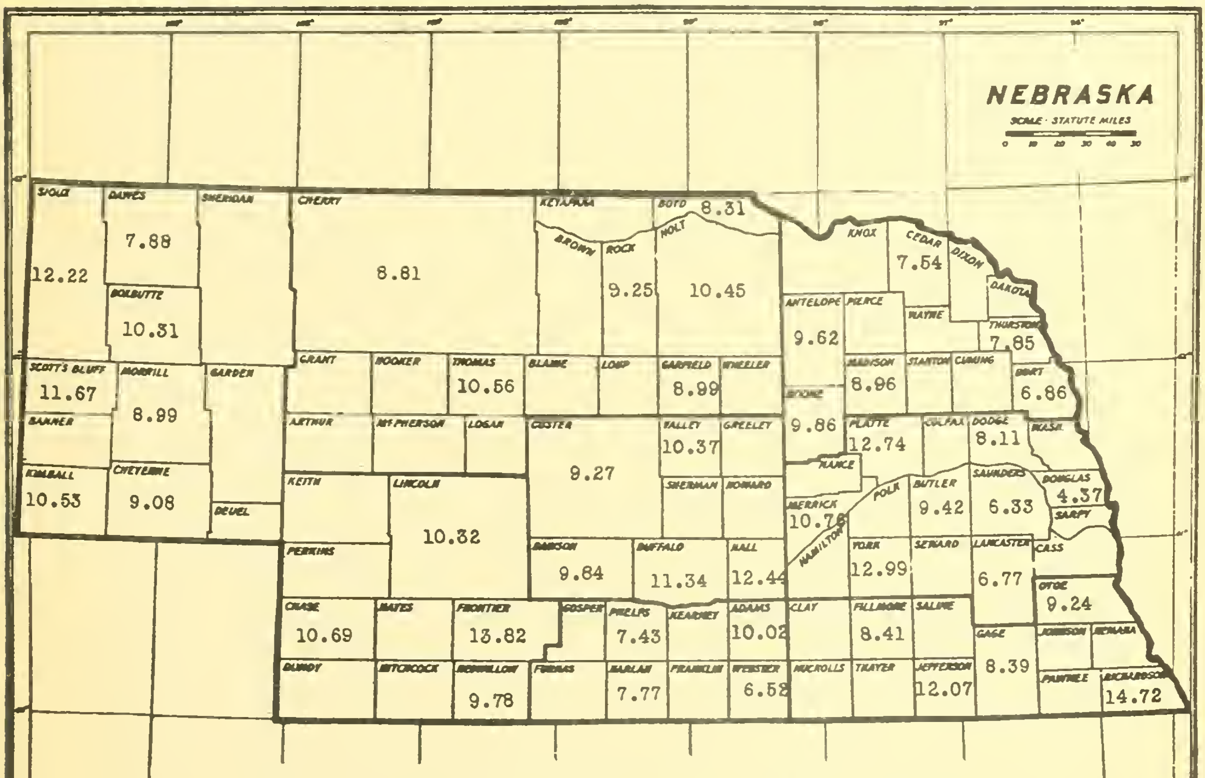

Fig. 2. Total precipitation from April 1 to May 31, 1935, at
a number of points in Nebraska.

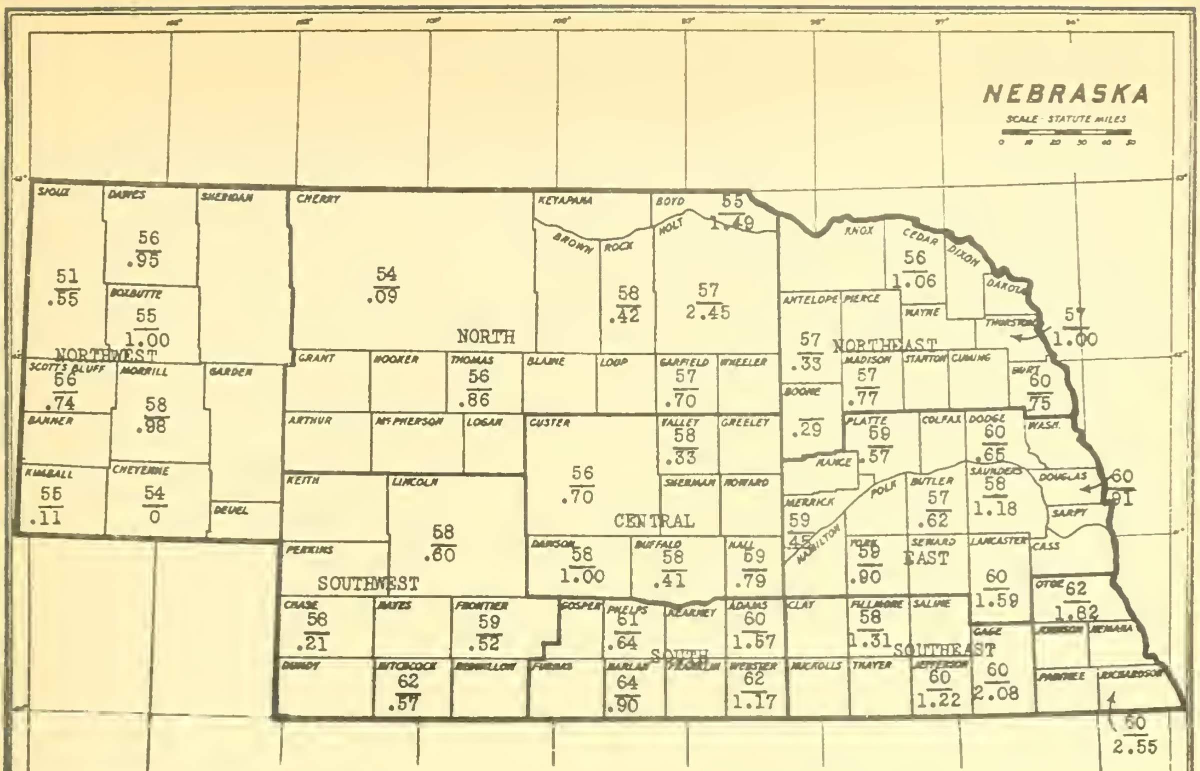

Fig. 3. Mean temperatures (above) and total precipitation (below) for the week of June 1 to 7, 1935.

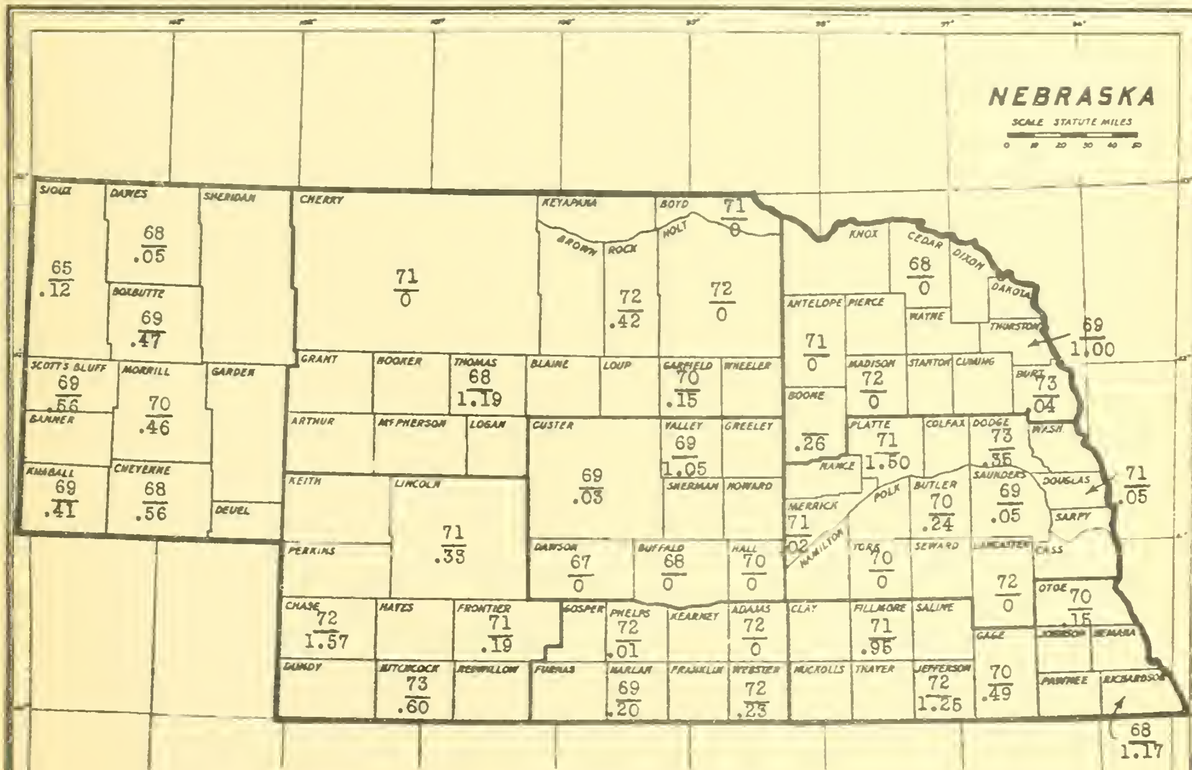

Fig. 4. Mean temperatures (above) and total precipitation (below) for the week of June 8 to 14, 1935.

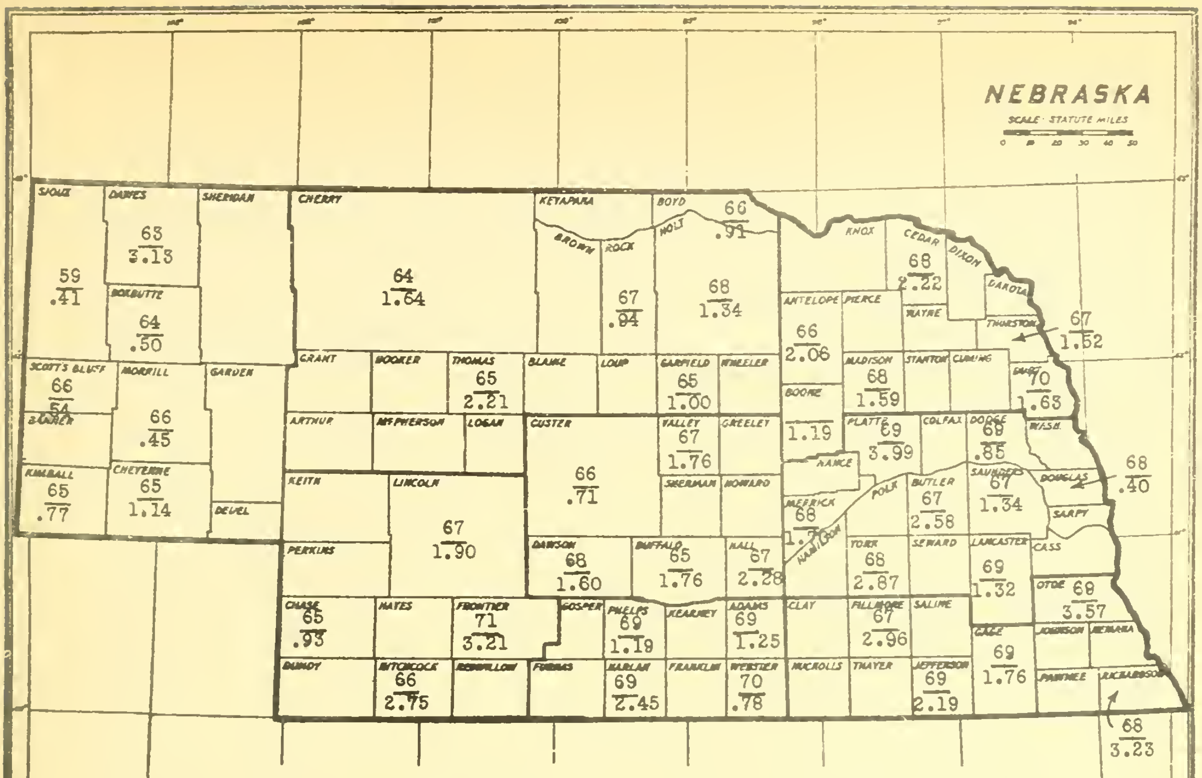

Fig. 5. Mean temperatures (above) and total precipitation (below) for the week of June 15 to 21, 1935.

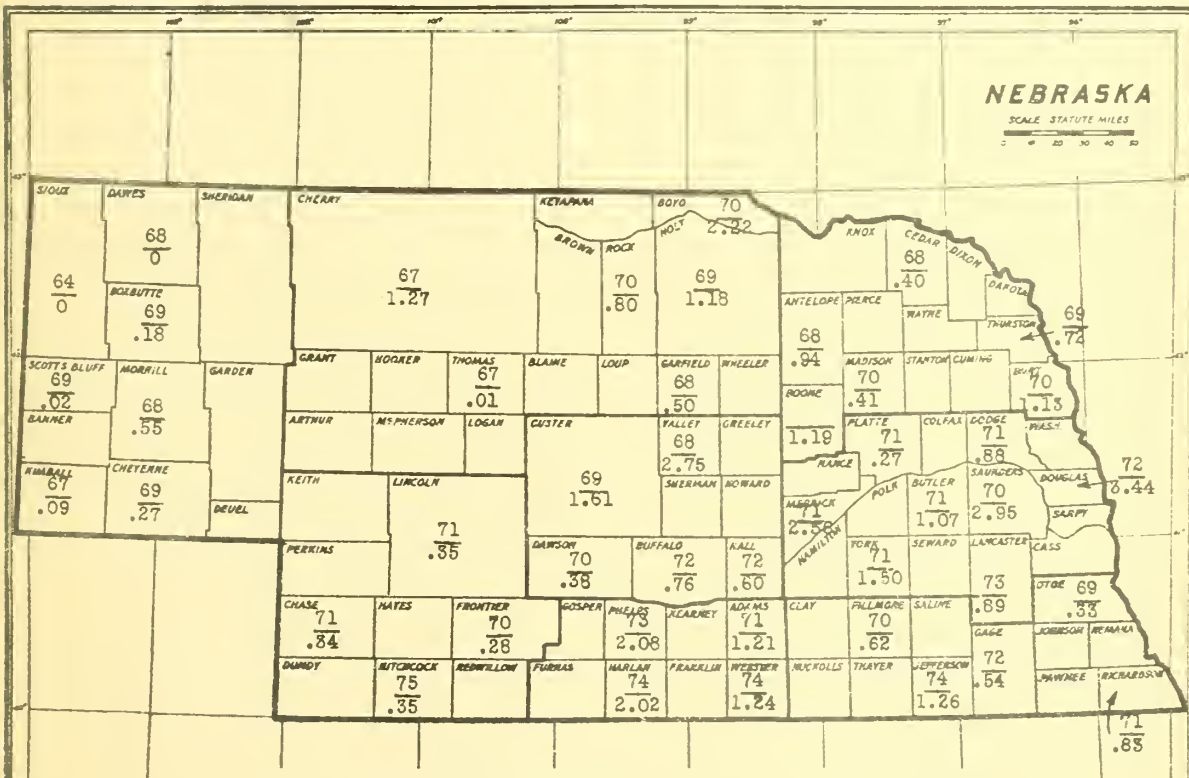

Fig. 6. Mean temperatures (above) and total precipitation (below) for the week of June 22 to 28, 1935.

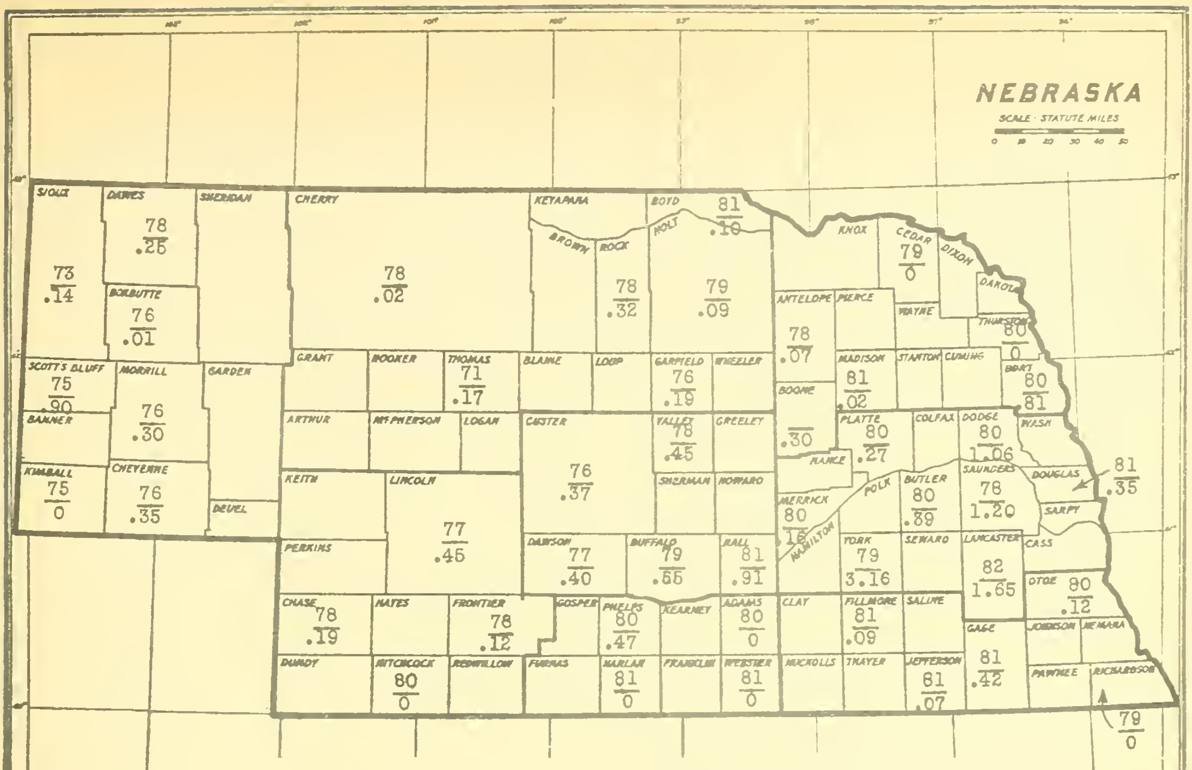

Fig. 7. Mean temperatures (above) and total precipitation (below) for the week of June 29 to July 5, 1935

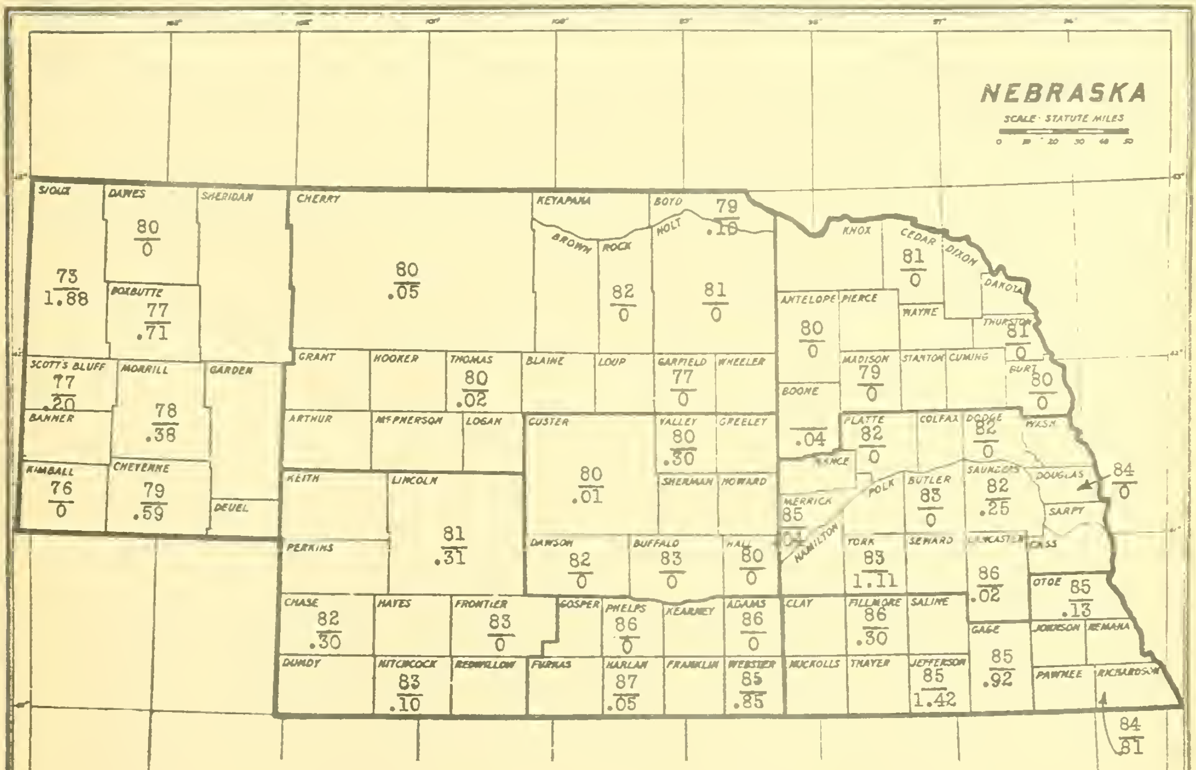

Fig. 8. Mean temperatures (above) and total precipitation (below) for the week of July 6 to 12, 1935.

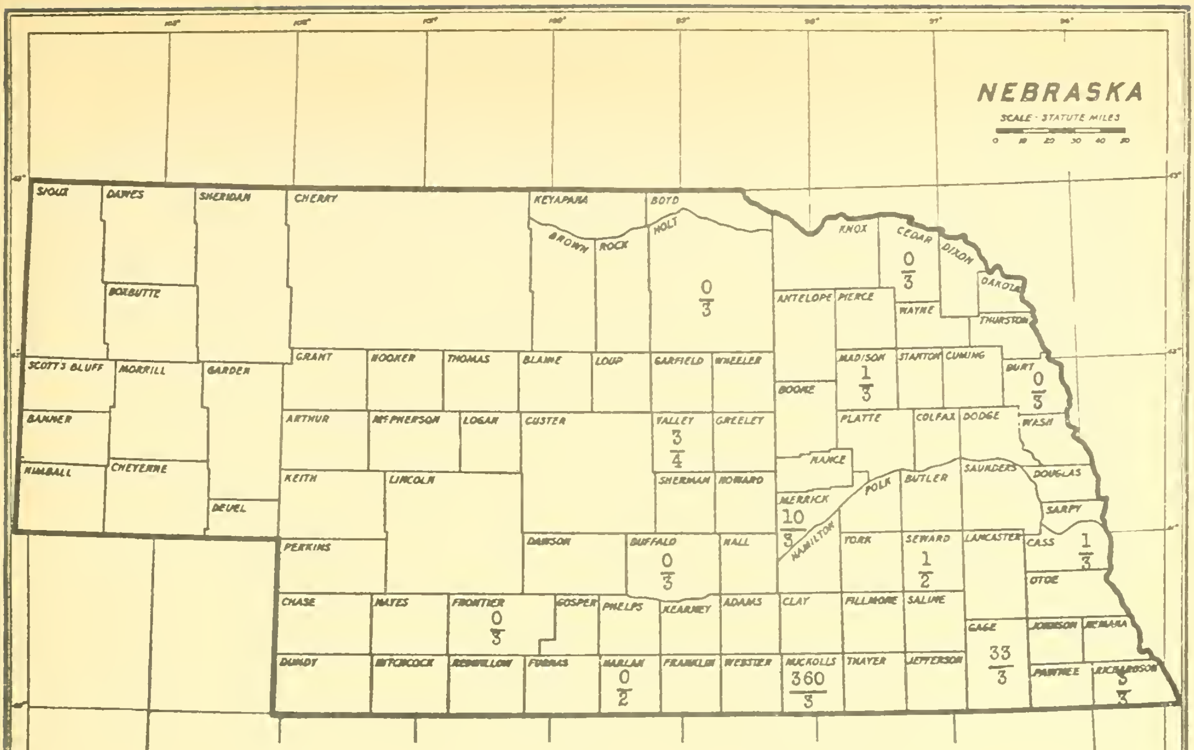

Fig. 9. The total number of stem rust urediospores (above) caught by 24-hour slide exposures (below) during the week of May 15 to 21, 1935.

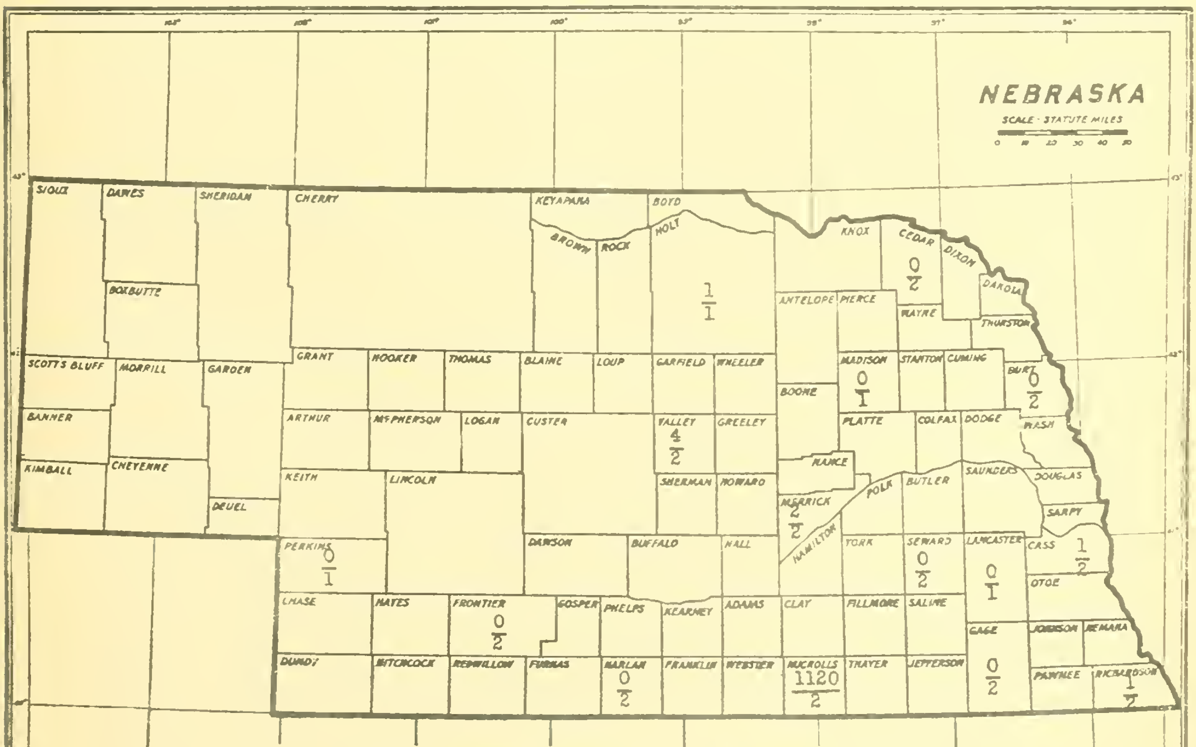

Fig. 10. The total number of stem rust urediospores (above) caught by 24-hour slide exposures (below) during the week of May 22 to 28, 1935.

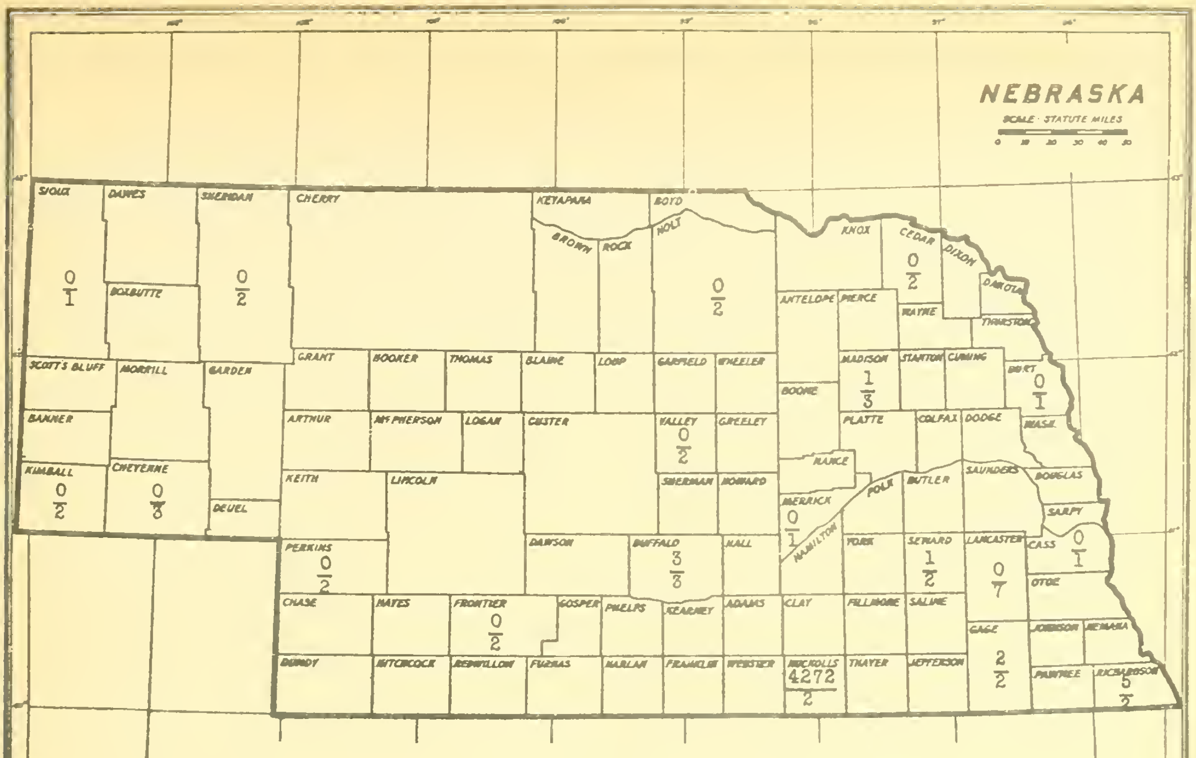

Fig. 11. The total number of stem rust urediospores (above) caught by 24-hour slide exposures (below) during the week of May 29 to June 4, 1935.

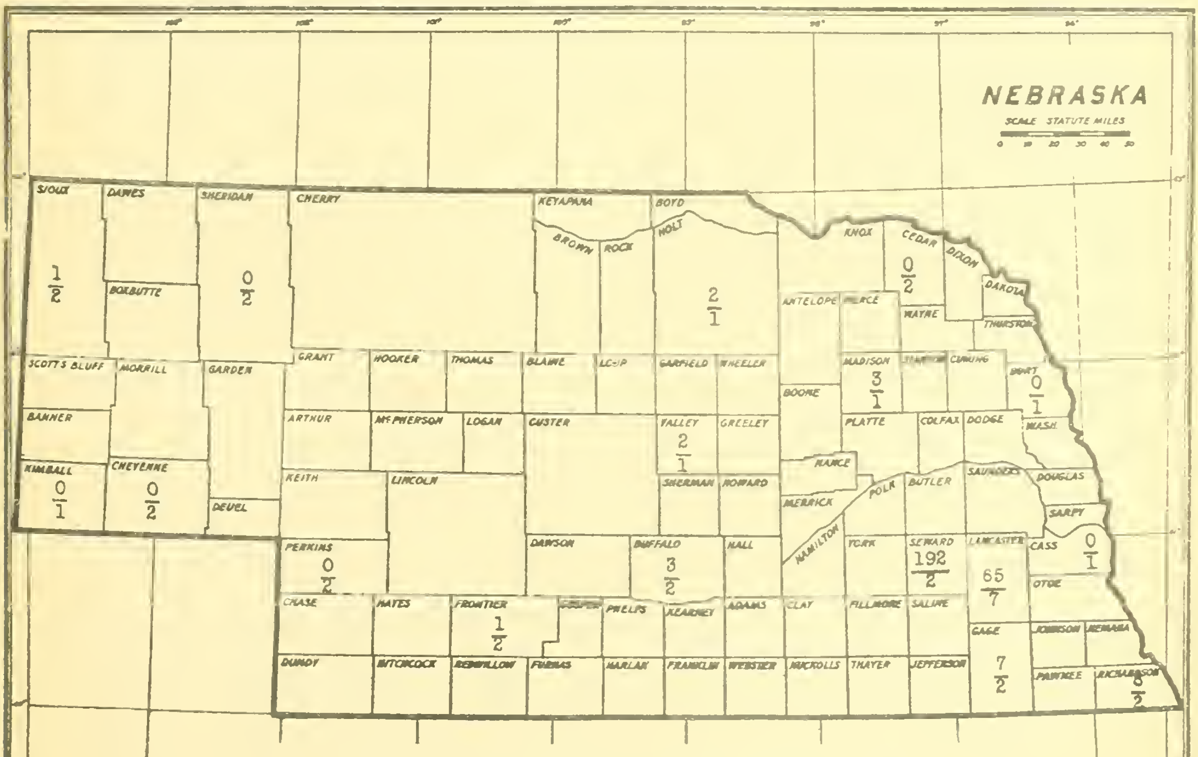

Fig. 12. The total number of stem rust urediospores (above) caught by 24-hour slide exposures (below) during the week of June 5 to 11, 1935.

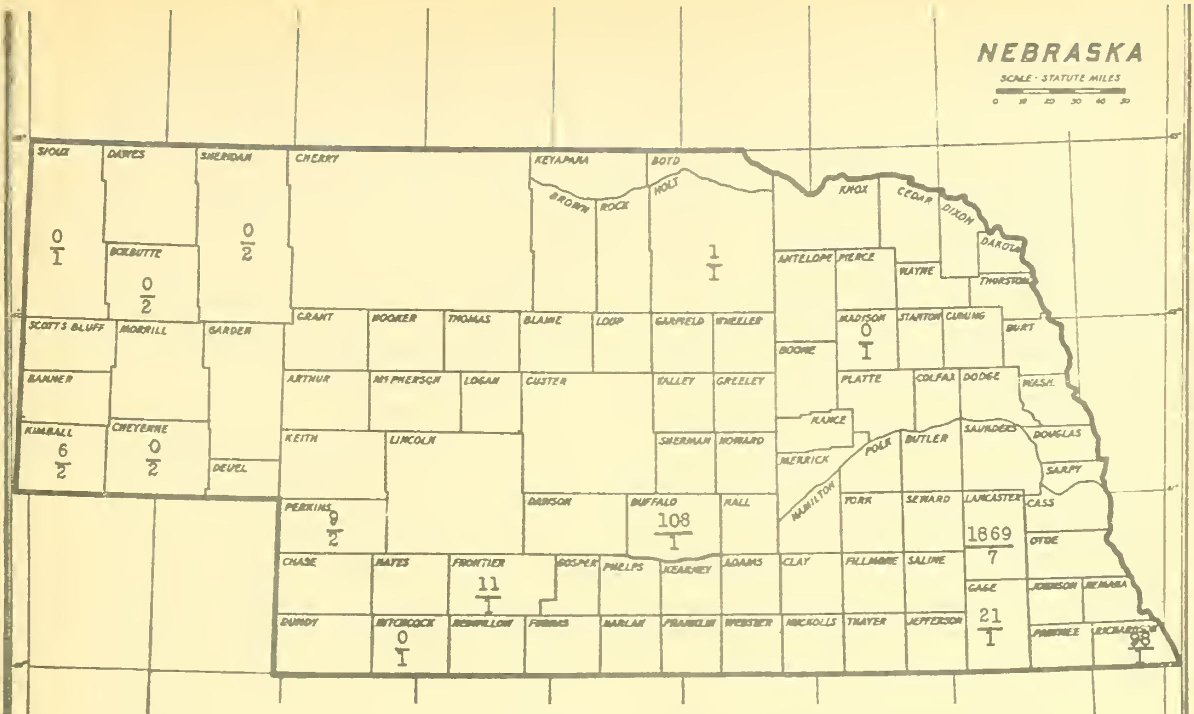

Fig. 13. The total number of stem rust urediospores (above) caught by 24-hour slide exposures (below) during the week of June 12 to 18, 1935.

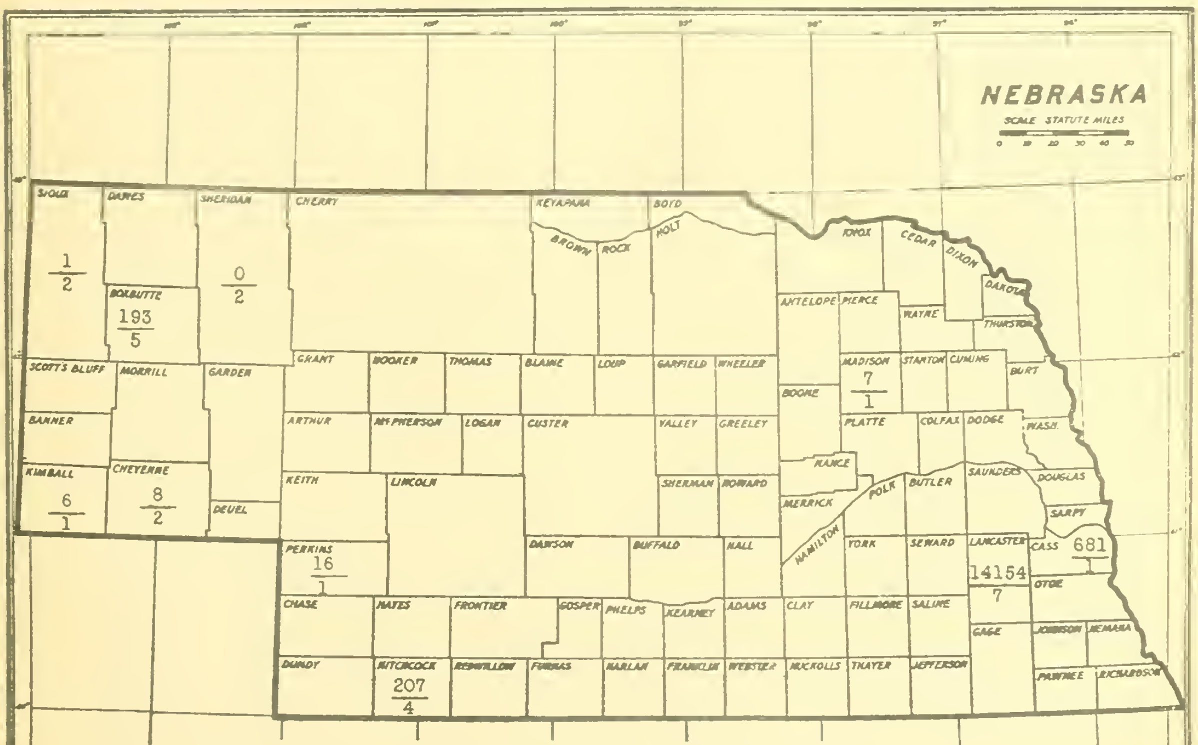

Fig. 14. The total number of stem rust urediospores (above) caught by 24-hour slide exposures (below) during the week of June 19 to 25, 1935.

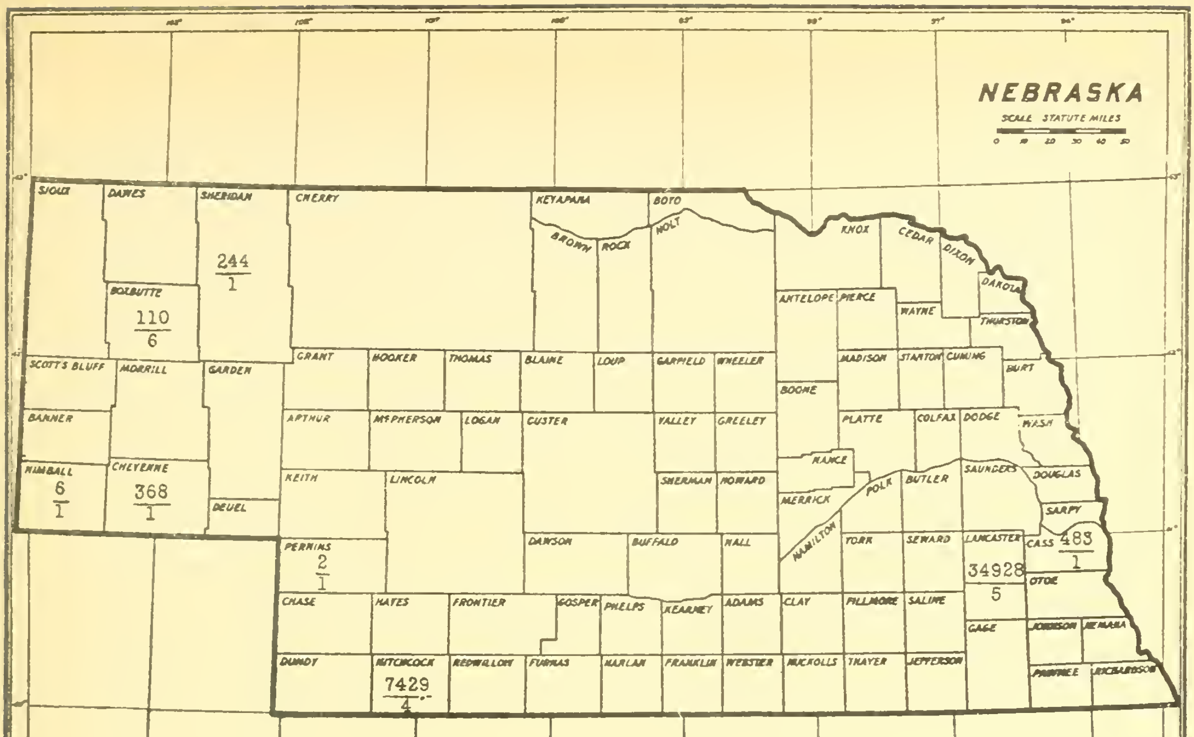

Fig. 15. The total number of stem rust urediospores (above) caught by 24-hour slide exposures (below) during the week of June 26 to July 1, 1935.

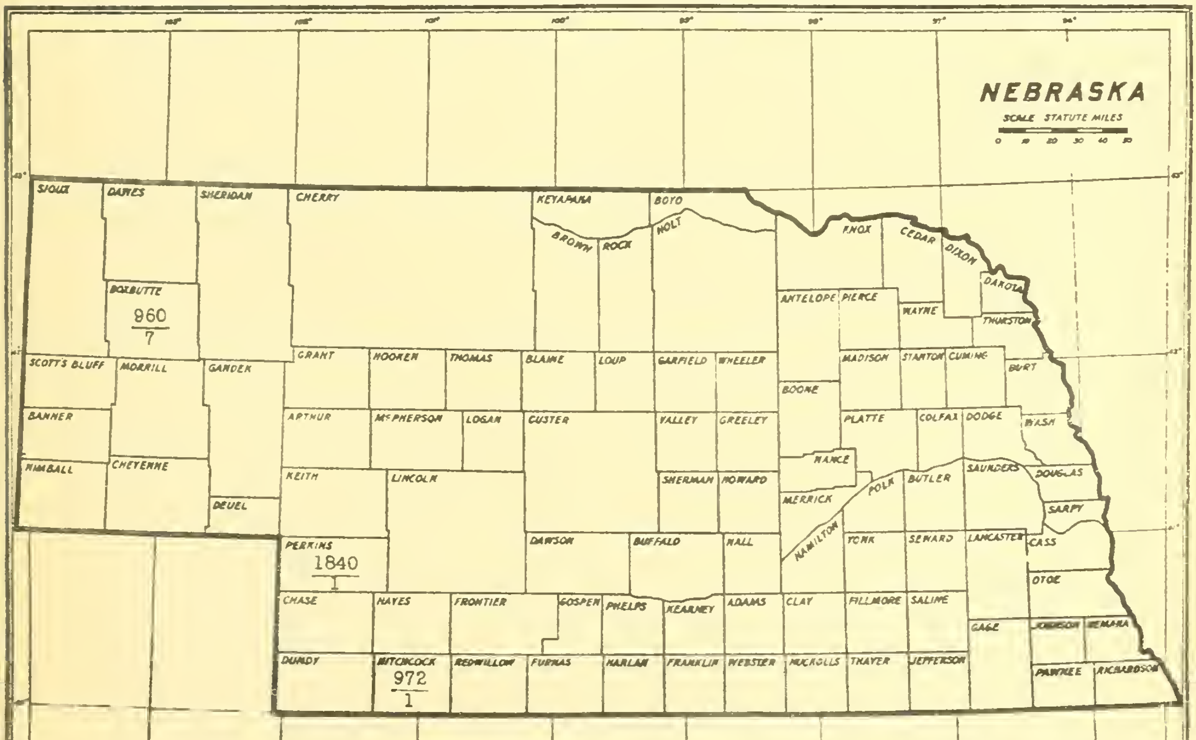

Fig. 16. The total number of stem rust urediospores (above) caught by 24-hour slide exposures (below) during the week of July 2 to July 8, 1935.

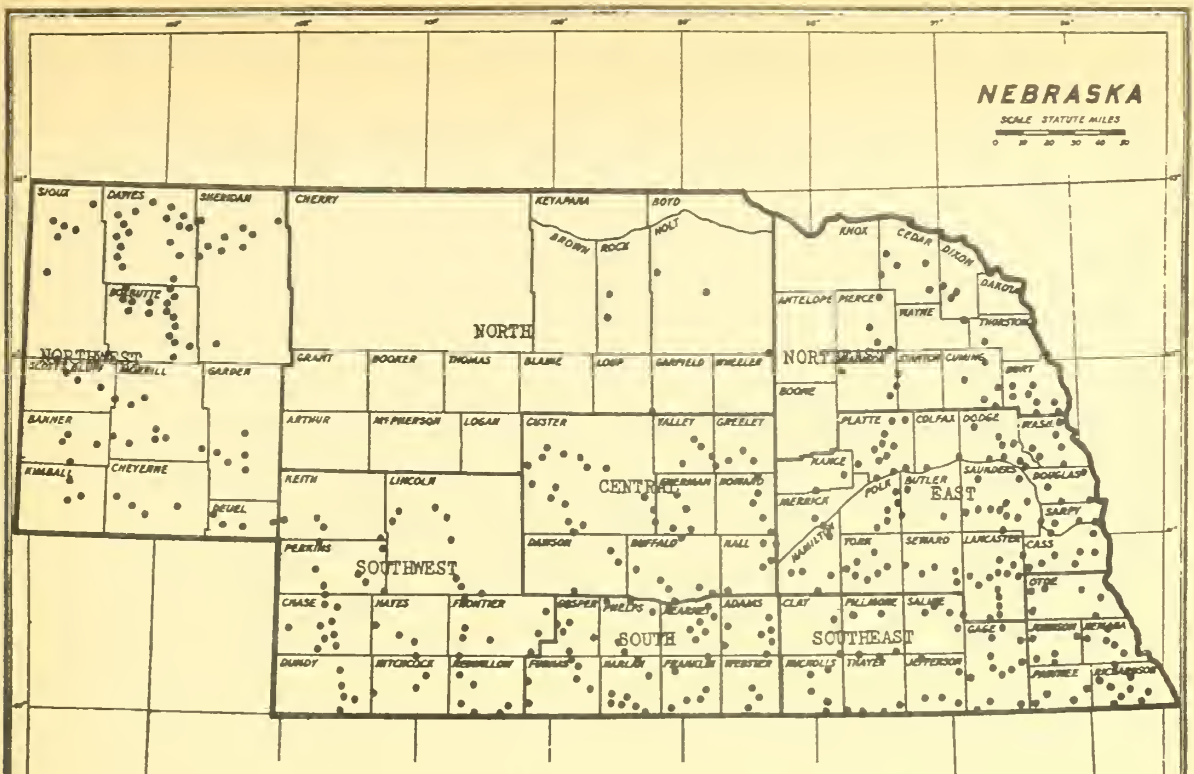

Fig. 17. Localities from which more than 600 stem rust collections were obtained in 1935.

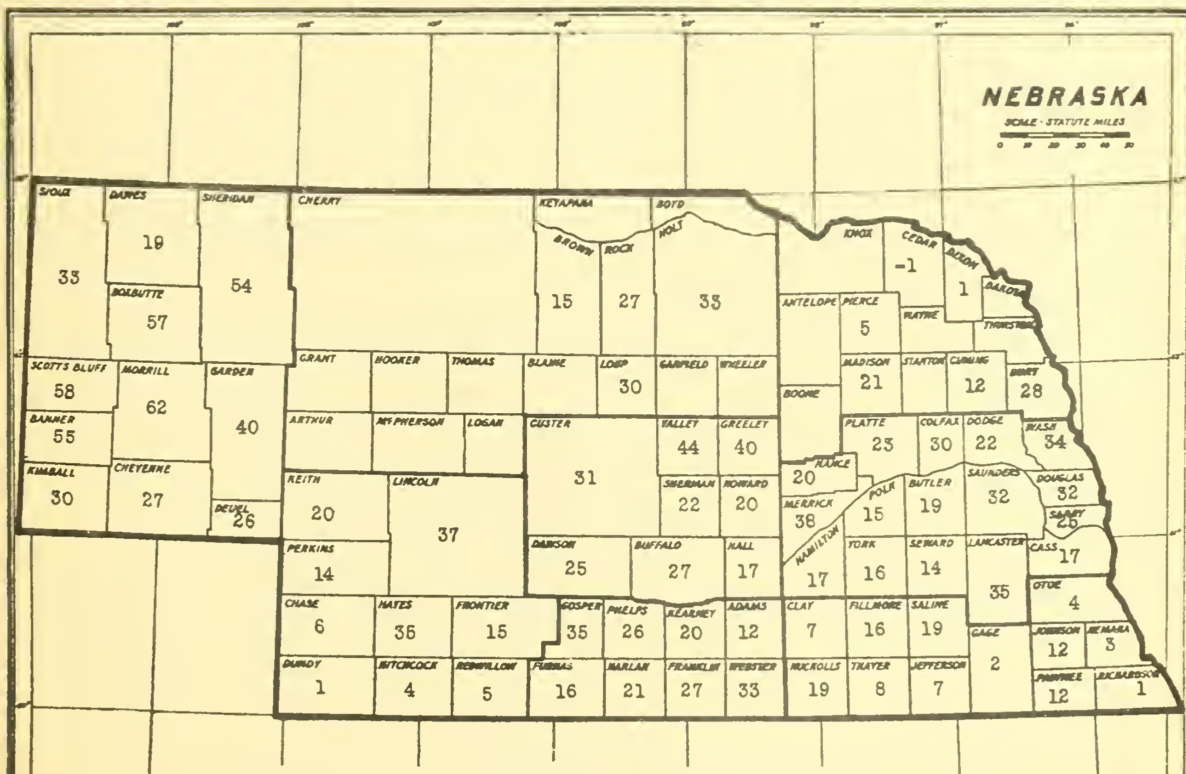

Fig. 18. The relative severity in percent of wheat stem rust by counties in 1935.

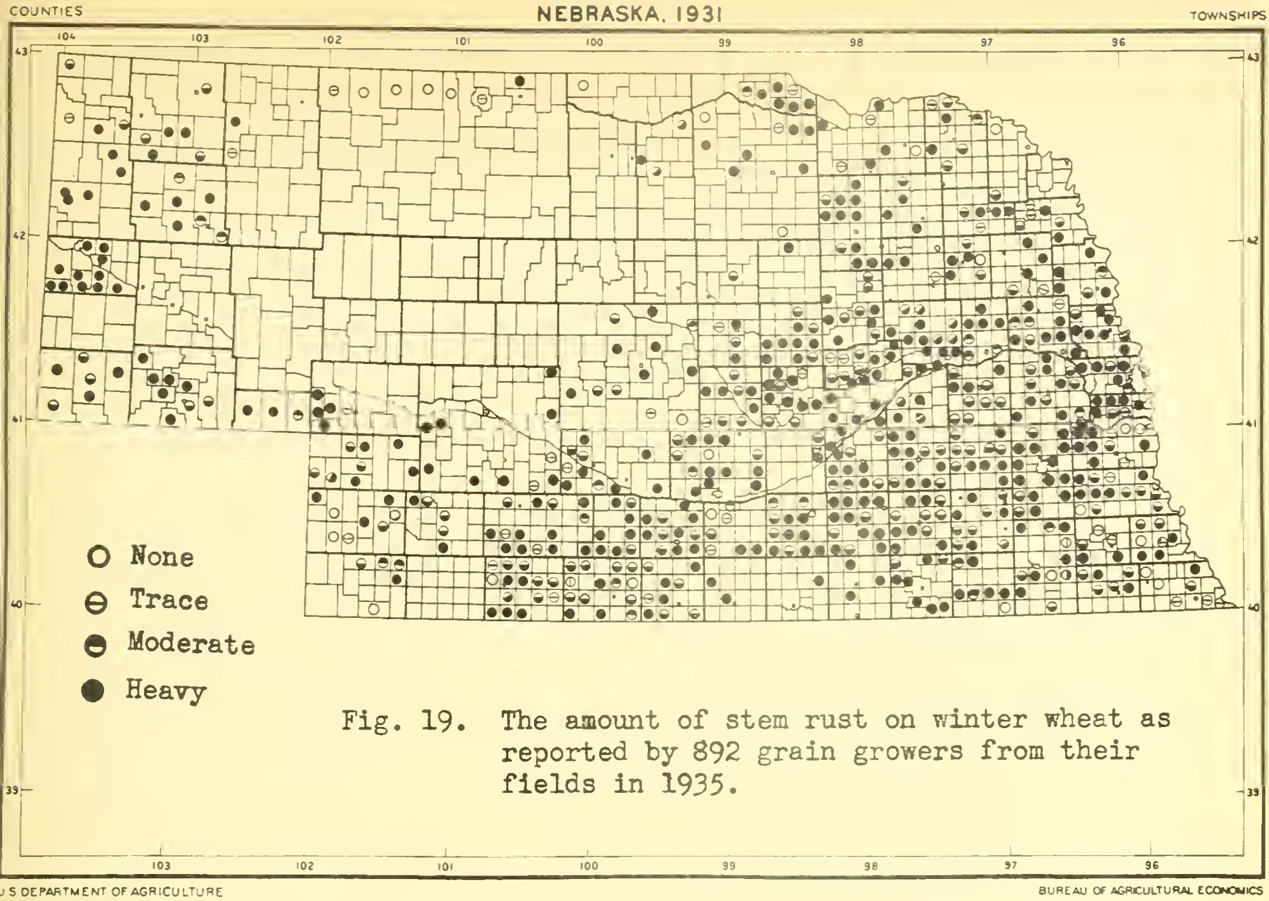

Fig. 19. The amount of stem rust on winter wheat as reported by 892 grain growers from their fields in 1935.

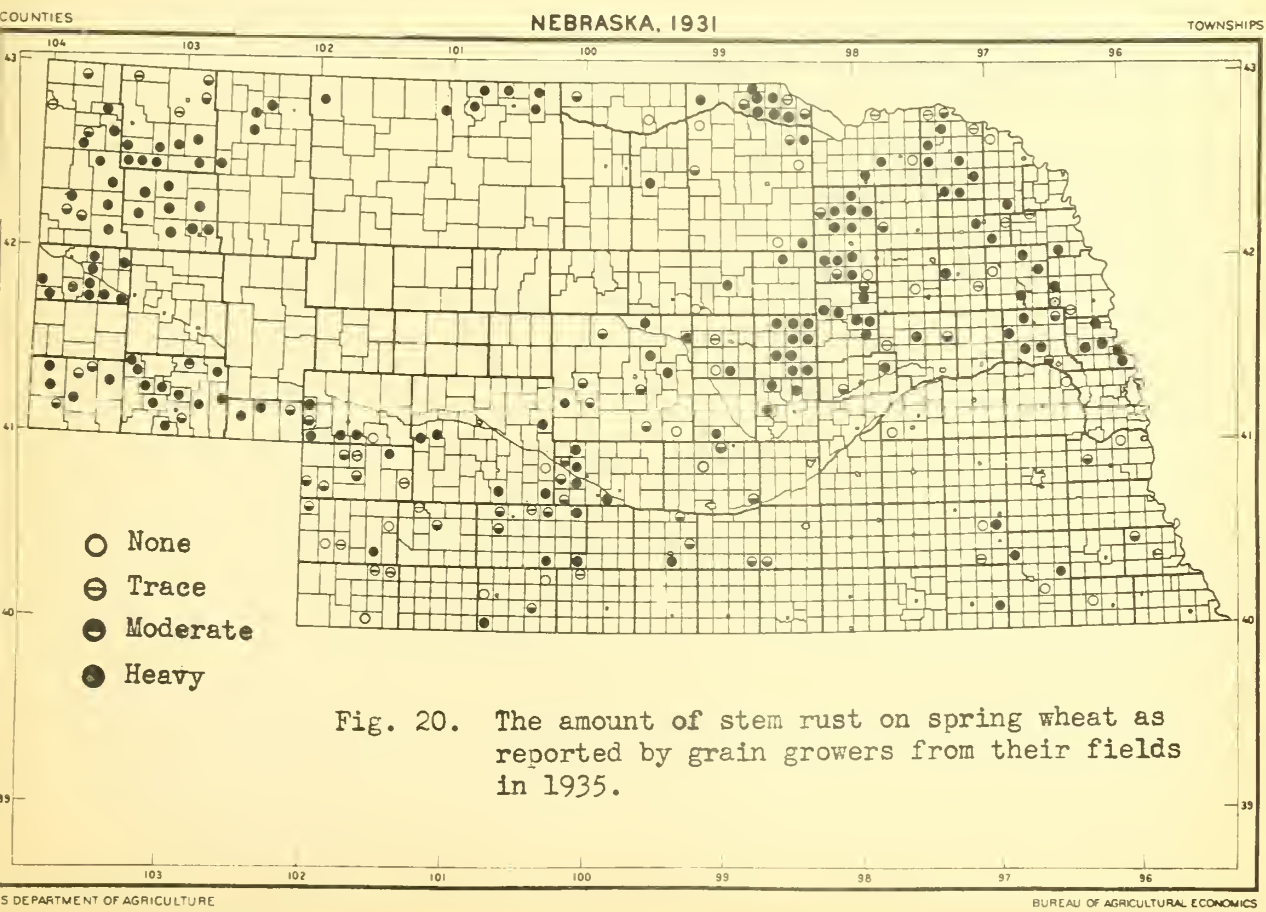

Fig. 20. The amount of stem rust on spring wheat as reported by grain growers from their fields in 1935.

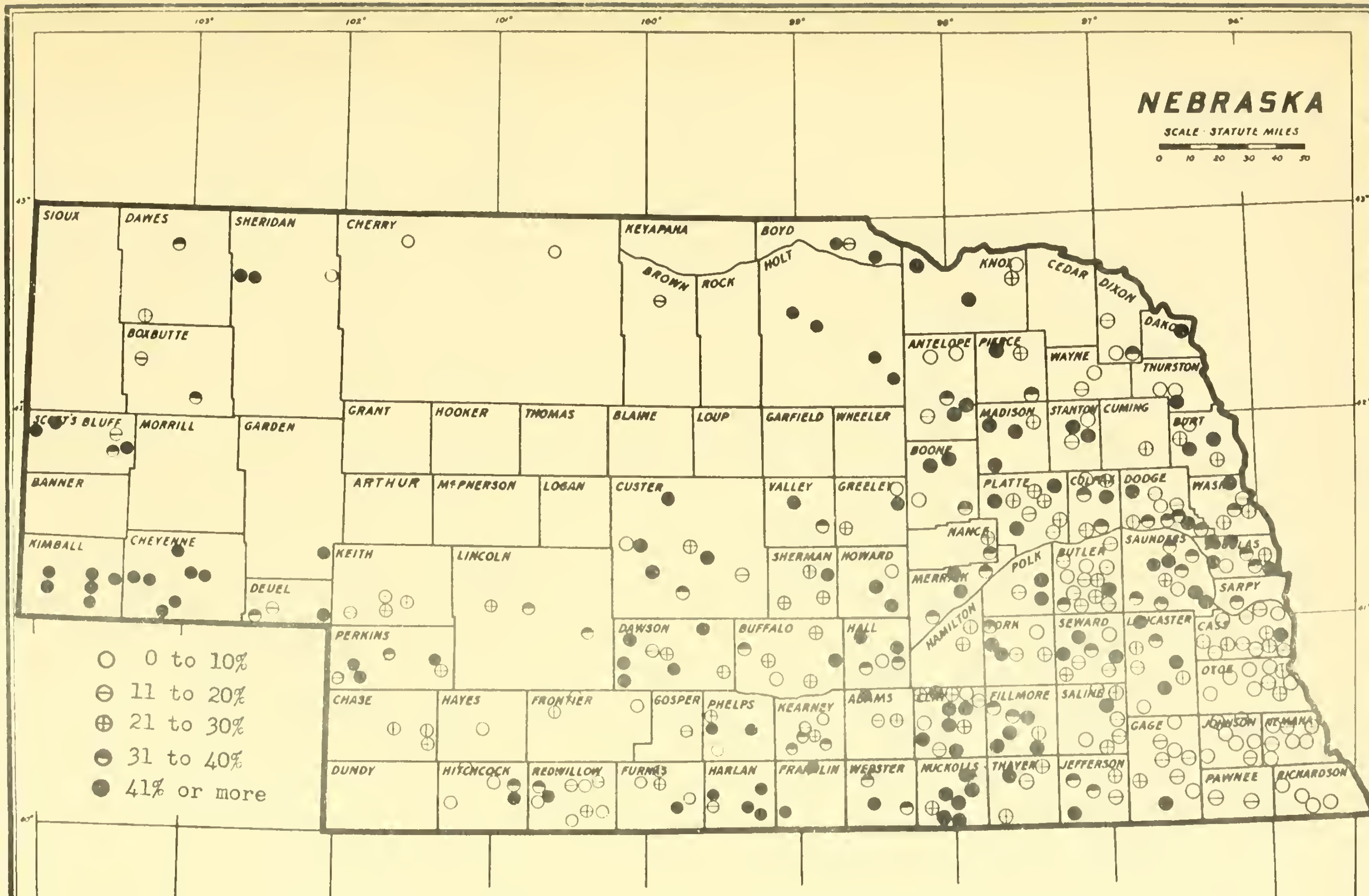

Fig. 21. The estimated wheat stem rust losses as reported by the grain dealers in 1935.

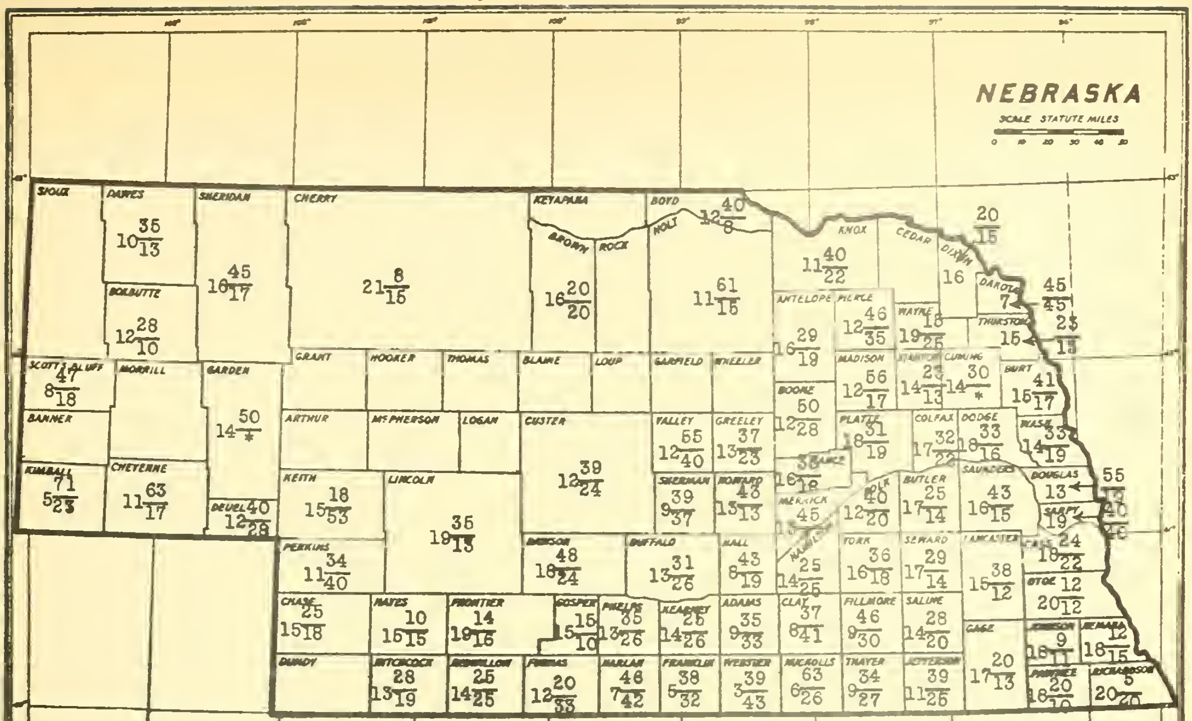

Fig. 22. The yield per acre in bushels, the percentage of loss attributed to stem rust (above), and the percentage of loss through heat (below), as estimated by the grain dealers for winter wheat in 1935.

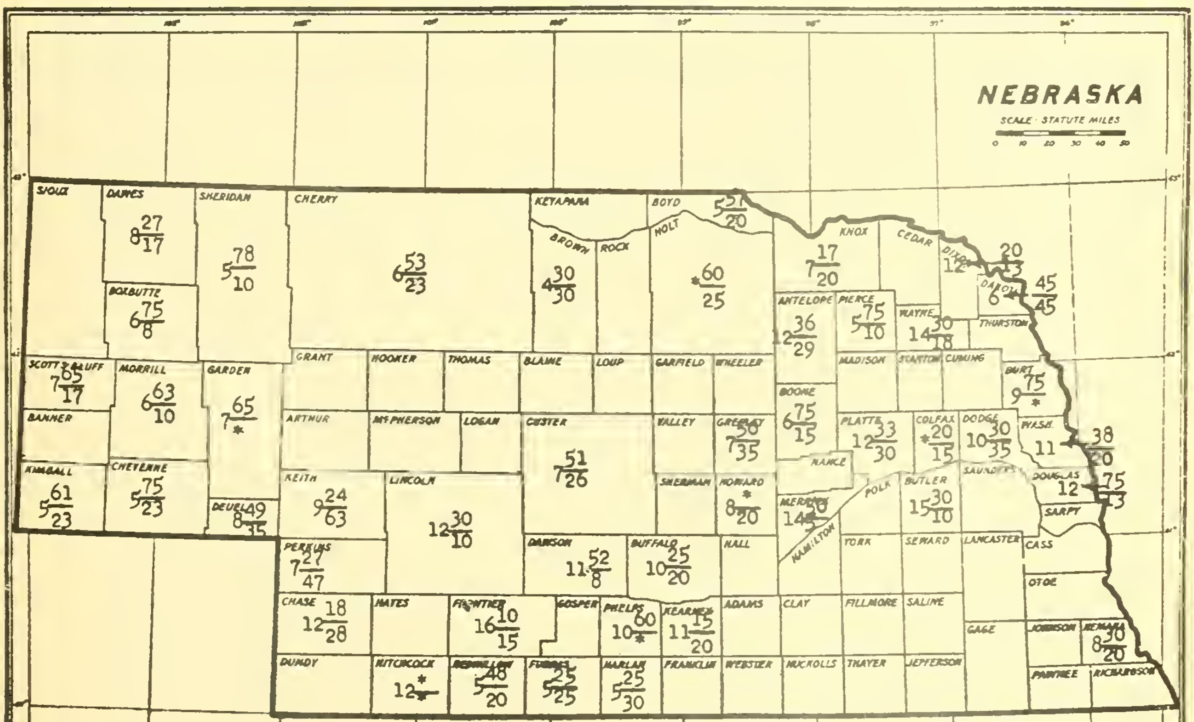

Fig. 23. The yield per acre in bushels, the percentage of loss attributed to stem rust (above), and the percentage of loss through heat (below), as estimated by the grain dealers for spring wheat in 1935.

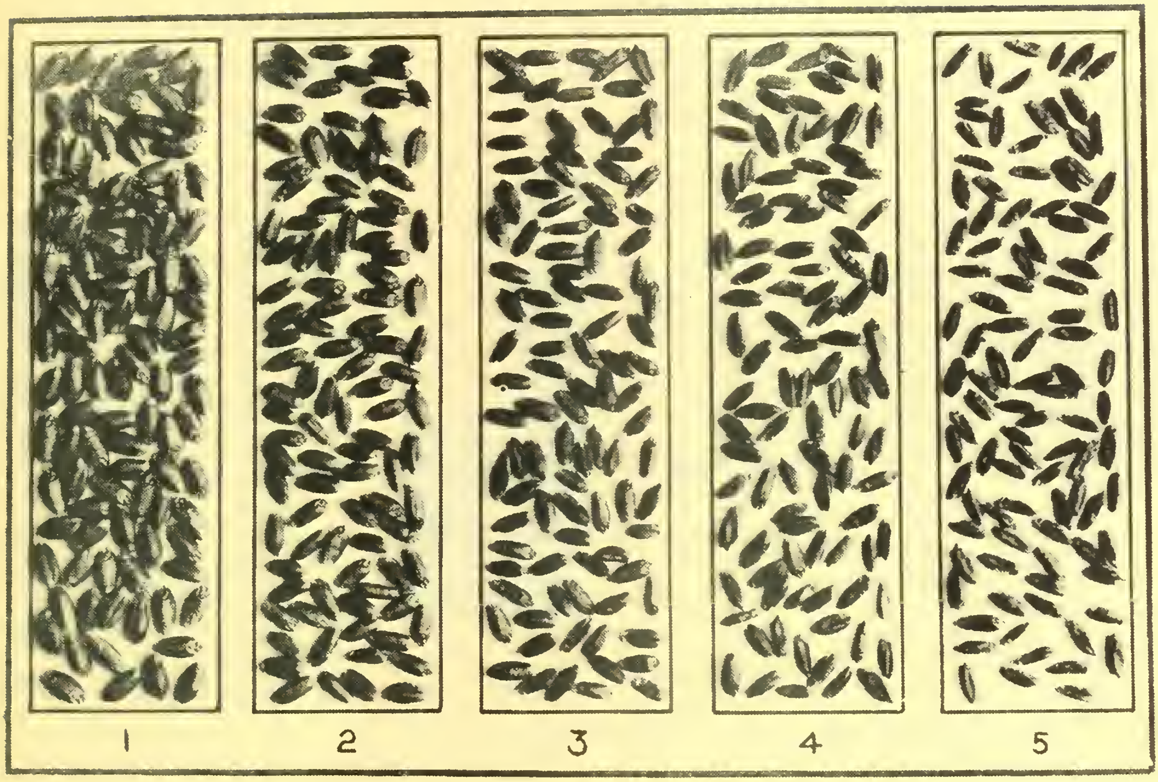

Plate I. Scale used in estimating the degree of shriveling in the wheat samples collected in Nebraska during 1935. The photograph shows five arbitrary degrees of shriveling from plump to badly shriveled berries. There are 100 kernels in each grade.